Méthodologie de qualification de site de mesures en réseau d'assainissement : Application à la débitmétrie en collecteur d'assainissement

H. Bonakdari, F. Larrarte, C. Joannis, Daniel Levacher

Methodology for qualifying measurement sites within a drainage network: Application to flow readings in a main drain

Hossein BONAKDARI
Université de Razi, Kermanshah, Iran
LCPC, Centre de Nantes, France
Frédérique LARRARTE*
Claude JOANNIS
LCPC, Centre de Nantes, France
Daniel LEVACHER
M2C UMR 6143 CNRS, Caen, France

ABSTRACT

In order to satisfy regulatory, technical and financial objectives, an increasing number of measurement devices have been installed in drainage networks. Yet the hydraulic conditions necessary for their effective operations, such as the choice of adapted pipe sections, can prove difficult to obtain since the performance of available equipment relies upon actual flow conditions. The research proposed herein makes use of a numerical tool in the aim of studying the influence of a change in hydraulics on velocity fields, thereby yielding the results expected subsequent to sensor placement. This article presents the methodology followed by an application example devoted to measuring flows within a storm drain. In order to carry out a continuous monitoring of pollutant flows, the installation of turbidity meters has been envisaged, yet water height remains rather low. This article reveals the benefits associated with a numerical study that enables examining the influence of a weir on raising the water surface profile so as to obtain adequate height for installing a turbidity meter, in addition to determining the site for setting up a Doppler sensor to generate measurements representative of average velocity. The initial set of flow metering results will also be provided.

Méthodologie de qualification de site de mesures en réseau d'assainissement – Application à la débitmétrie en collecteur d'assainissement

RÉSUMÉ

Afin de répondre à des objectifs réglementaires, techniques et financiers, de plus en plus d'appareils de mesure sont installés en réseau d'assainissement. Mais les conditions hydrauliques nécessaires à leur fonctionnement tout comme le choix des sections adaptées peut s'avérer délicat car les performances des matériels disponibles sont tributaires des conditions d'écoulement. Les recherches proposées utilisent l'outil numérique dans le but d'étudier l'influence d'une modification du contexte hydraulique sur les champs de vitesses et donc les résultats que l'on peut attendre suite à la mise en place de capteurs. Cet article présente la méthodologie puis un exemple d'application à la mesure des flux dans un collecteur pluvial. Afin d'effectuer un suivi en continu des flux polluants, la mise en place de turbidimètres est prévue mais la hauteur d'eau est faible. L'article montre tout l'intérêt d'une étude numérique qui a permis, d'une part, l'étude de l'influence d'un seuil sur le relèvement de la ligne d'eau afin d'avoir une hauteur suffisante pour installer un turbidimètre et, d'autre part, la détermination du lieu d'installation d'un capteur à effet Doppler afin d'obtenir des mesures représentatives de la vitesse moyenne. Les premiers résultats de débitmétrie sont détaillés.

*CORRESPONDING AUTHOR:
Frédérique LARRARTE
frederique.larrarte@lcpc.fr

INTRODUCTION

While an efficient control over drainage networks serves as one of the main components of water resource management policy in cities both now and for the future **[1]**, actual operations of the systems involved often deviates greatly from the set of hypotheses developed during network design. As such, *in situ* measurements need to be conducted in order to first comprehend and then remedy drainage operations. These measurement networks constitute a valuable monitoring and oversight tool, whose benefit becomes fully tangible in the case of a continuously-monitored system. Moreover, a stricter regulatory context (joint ministerial decree adopted on December 22, 1994) and more stringent standards **[2-4]** now require water resource managers to supervise networks, assess their performance, take action quickly in the event of isolated malfunctions, and inform the utility owner of improvements likely to enhance efficiency and increase collection reliability. Even though the introduction of sensors has become a more widespread practice, the challenge still lies in finding sites that fulfill the professional guidelines and use conditions, such as a rectilinear pipe section without any deposits, that offer the right safety environment for both personnel and equipment **[5]**.

In the aim of helping practices evolve, a measurement site qualification methodology has been developed within the scope of research conducted on pollutant flows within urban wastewater systems **[6]**. This methodology must enable the following:

– determining whether a potential site is *a priori* favorable or, on the other hand, requires additional investigation;
– qualifying measurement sites;
– defining the installation protocol for a given sensor;
– specifying the procedure for interpreting results output by sensors, so as to facilitate the conversion from measured values to the targeted physical magnitudes;
– evaluating the precision of data provided from existing sites.

This article will first present the various steps of the methodology before displaying an application to the case of sensor installation within a storm drain.

METHODOLOGY

The implementation of measurement networks proves to be a major component in the management policy adopted for sewer/drainage systems **[7]**. Interpreted with a certain time delay, these measurement results offer precise indications of network performance at the scale of a full year of operations and serve to define a set of indicators relative to wastewater discharge, effluent quality entering the treatment plant and the state of facilities **[8]**. Moreover, some sensors may be connected as input to the real-time management system, for the purpose of ensuring efficient facility operations or optimal use of facility capacity under the specific set of circumstances, particularly during rainfall events.

Designing a measurement network necessitates an in-depth preliminary assessment that includes:

• a clear definition of objectives, for the purpose of deducing the general location of measurement points as well as target parameters;
• precise specifications of measurement sections, along with the methods and technologies to be applied;
• sensor installation layout and the set of computations to be performed on the raw data in order to obtain the information sought.

Moreover, the choice of measurement section must include other constraints as well, such as access potential from the surface, safety problems, and connection to the energy and telecommunications networks. These considerations are bound not only by the requirement to match the measurand range with that of the measurement device, but also by capital investment and operating cost requirements that tend to be quite strict.

These practices, on the whole, prove satisfactory yet a number of difficulties still need to be overcome. The flow meters used in a sewer network serve to determine flows based on a measurement of both velocity and height. While water heights are generally read without encountering problems, velocity measurements often entail complications. For this reason, our efforts until now have focused on the velocity determination: our approach is based on application of the hydrodynamic model to configure the measurement points best suited for sewer/drainage networks. The emphasis lies in streamlining guidelines relative to the proximity of a unique point and, if necessary, to loosen these guidelines so as to tolerate measurements at inappropriate sites, while maintaining control over the level of uncertainty in the results obtained. For more complex pipe sections, it is also intended to replace or complete the *in situ* experimental calibration by a *numerical* calibration. Nonetheless, this model set-up is not straightforward within the operational context of laying out measurement networks, for which the amount of resources allocated remains rather limited.

An intermediate methodology has been developed between the somewhat empirical current practices and a systematic modeling of measurement sites. **Figure 1** depicts this methodology in detail, with the key step being the second one. The process calls for searching in generic models whether a case similar to that of the site anticipated in Step 1 has already been treated. If so, Step 3 consists of transposing results from the generic configuration to the selected site, which then allows during Step 4 to either reject the designated site and repeat the process as of Step 0, or qualify the site and proceed directly to Step 5 of the measurement point set-up procedure, or consider the case suspect. At this juncture, a specific model may be employed.

IMPLEMENTATION OF THE METHODOLOGY

The LCPC's Water and Environment Division is conducting research on the hydrological assessment of an urban catchment basin. Their work program calls for measuring flow rates and pollutant loads within both the stormwater and sewer networks. For the sake of clarity, let's limit the present discussion to the stormwater network. The objective, i.e. Step 0 of the methodology (as diagrammed in **Figure 1**), is therefore to measure flow rates and pollutant loads. At the level of the candidate site, i.e. Step 1, the choice focuses on the outfall, which is the network point furthest downstream. Network drawings were supplied by the utility authority, the Nantes Metropolitan Council. These plans indicate a stormwater drain with a 1.20-m diameter circular cross-section. Field visits were then organized to characterize site hydraulics, revealing the presence during dry weather periods of a flow with a water height of between 0.05 and 0.10 m at a velocity of $0.10\ m \cdot s^{-1}$, i.e. a dry weather flow rate of less than $4.5 \times 10^{-3} m^3 \cdot s^{-1}$. During rainy weather, water height in the drain pipe exceeds 0.25 m even during ordinary rainfall events. The laboratory's assessment objective requires continuous measurements, whereas the Doppler flow meters planned for site instrumentation only operate appropriately for water heights of at least 0.15 m. Moreover, the ongoing monitoring of pollutant loads has necessitated introducing a turbidity meter, yet its implementation implies a high enough water level to immerse the sensor cells. The assessment by the end of Step 1 indicates that the candidate site does not enable, in its current state, carrying out the programmed set of measurements to satisfy the objective. It would thus be necessary to alter the site so as to raise the water surface profile and enable dry weather measurements. The decision was then made to introduce a weir. In support of this strategy, we proceeded to Step 2 and opting for a generic configuration, which resulted in a one-dimensional model of the water surface profile.

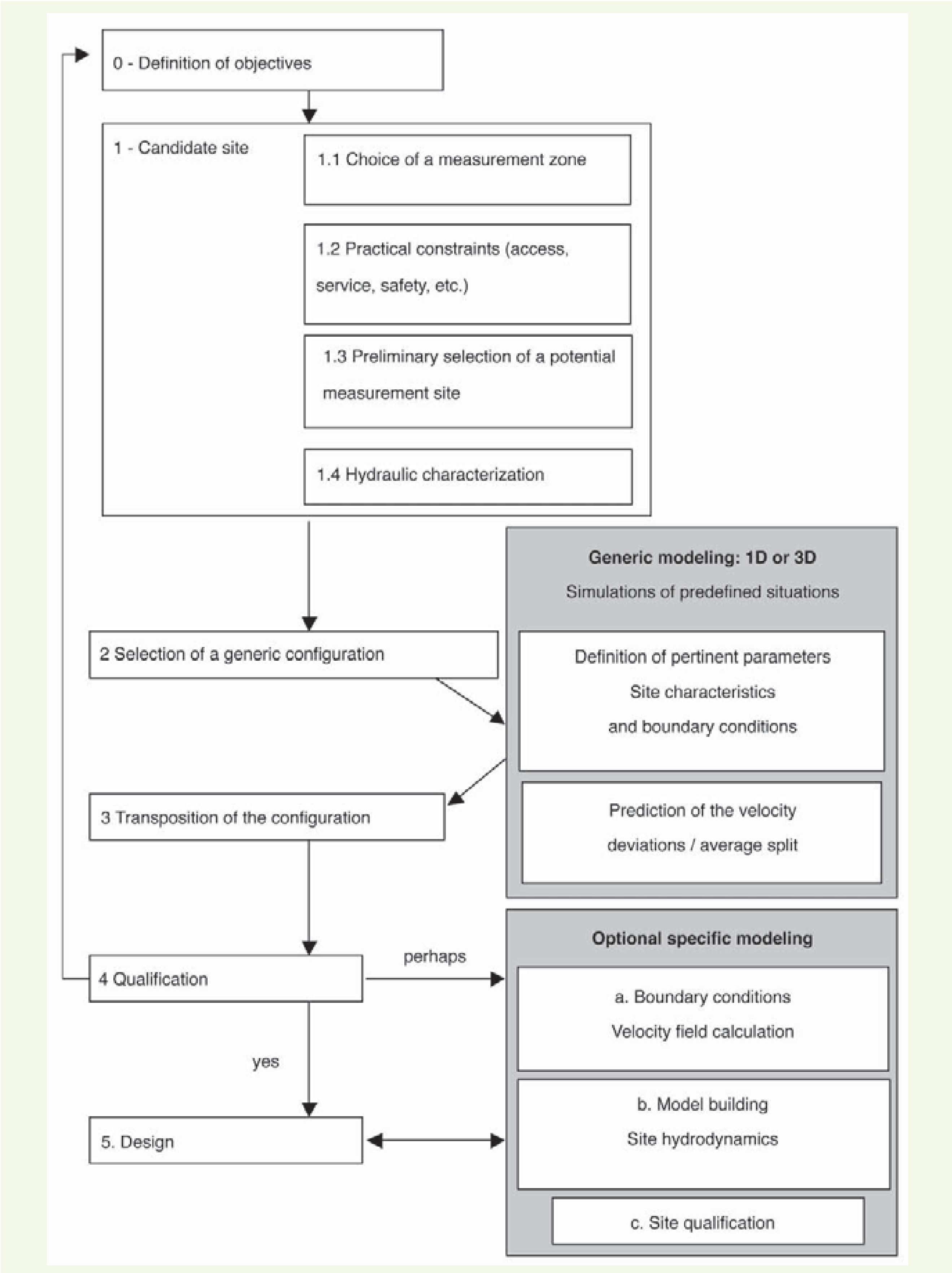


Figure 1
Detailed layout of the proposed methodology

Water surface profile modeling

Introducing a weir induces a gradually-varying flow path. This procedure entails searching for a solution to the problem of determining the free surface or water height h(x) according to the following equation:

$$\frac{dh(x)}{dx} = \frac{I - I_f}{I - F_r^2} \tag{1}$$

where x is the flow direction, I the pipe slope, I_f the energy surface slope, and F_r the Froude number. For the pipe section examined herein, the slope of the base plate equals 0.3%, hence normal height exceeds critical height. The flow is of the fluvial or subcritical type, i.e. indicating a Froude number of less than 1. In the presence of a weir, the water height tends towards the normal height of the channel as the distance upstream of the weir approaches infinity; this water height increases closer to the weir, with this type of profile being referred to as M1.

Figure 2 displays the trend in water surface profile within the channel upstream of the weir, with the M1 curve calculated using Euler's numerical method **[9]** for a flow rate of $4.5 \times 10^{-3}\ m^3 \cdot s^{-1}$. For this rate and in the absence of a weir, the water height equaled 0.10 m and the velocity $0.10\ m \cdot s^{-1}$ 25 m upstream. The turbidity meter therefore could not be installed. Once the weir is introduced, the water height for this same flow rate equals 0.21 m, yet velocity slows to $0.035\ m \cdot s^{-1}$. Larrarte *et al.* **[10]** demonstrated that Doppler flow meters do not function properly at such low flow velocities. It was thus decided to measure the higher flow rates with the Doppler flow meter and the lower rates with a spillway designed not to disturb flow meter measurements at the higher rates. This set-up has given rise to a specific model like the one proposed in the methodological guide (i.e. Step 4 of the qualification diagram shown in **Figure 1**).

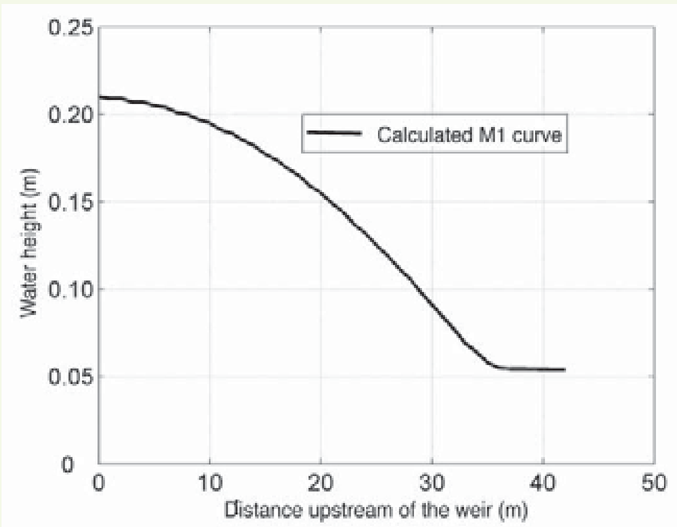
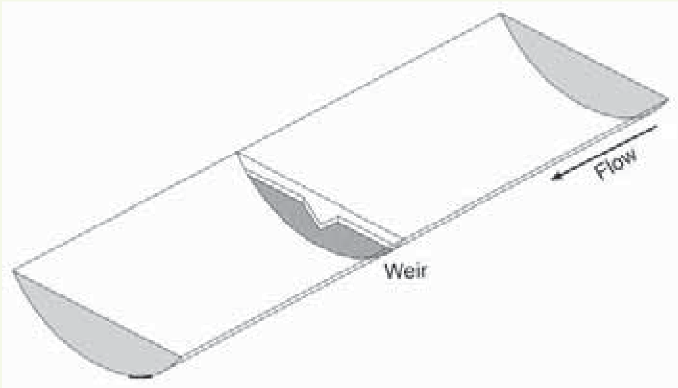


Figure 2
Evolution in the water surface profile upstream of the weir

Specific modeling set-up

Once this observation had been confirmed, the choice was oriented to a weir height value of 0.20 m via a V-shaped notch 0.19 m high with an apex angle of 70°. To accommodate the hydraulic context induced by introducing this weir, a three-dimensional flow model was applied to a 1.20-m diameter circular section pipe with a 0.3% slope, a water height equal to 0.10 m and a velocity $\overline{U} = 0{,}10\ m \cdot s^{-1}$ 30 m upstream. **Figure 3** presents the computation domain; this length was selected so as to yield, from the simple information on water height and velocity $\overline{U}$ in the upstream section, the field of velocities developed over the computation domain.

Figure 3
Weir diagram used in the circular drain pipe



The numerical study makes use of the CFX industrial code, which solves three-dimensional Navier-Stokes equations and enables calculating velocity fields within a straight vertical pipe section. The code employs a finite volume method based on tetrahedric control volumes and a structured Cartesian mesh. Hydraulic data are determined by solving a system of equations that includes the continuity equation and movement quantity equations.

In the study of turbulent flows, the statistical approach has been adopted. Each instantaneous field $\mathcal{F}$ is considered as the sum of an average field F and a turbulent fluctuation field f built around this average field, i.e.:

$$\mathcal{F} = F + f \qquad (2)$$

According to this approach, for each turbulent flow field, both an average value and a value corresponding to turbulent fluctuations can be derived. The corresponding average values are in turn defined by the following relations:

$$F = \frac{1}{\Delta t}\int_0^{\Delta t} \mathcal{F}\, dt \qquad (3)$$

$$\overline{f(t)} = \frac{1}{\Delta t}\int_0^{\Delta t} f(t)\, dt = 0 \qquad (4)$$

It should be pointed out that, by definition, the temporal average of fluctuations equals zero. By applying parametric decomposition, the equations of both mass conservation and movement quantity conservation can be rewritten for an incompressible flow through the relations listed below:

$$\frac{\partial U_i}{\partial x_i} = 0 \qquad (5)$$

$$\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\nu \frac{\partial U_i}{\partial x_j} - \overline{u_j u_j}\right) \qquad (6)$$

The terms $-\rho\overline{u_i u_j}$ form the Reynolds tensor, which is expressed as a function of the correlation tensor between fluctuating components of the velocity vector, i.e.:

$$-\rho\overline{u_i u_j} = -\rho\begin{pmatrix} \overline{u^2} & \overline{uv} & \overline{uw} \\ \overline{vu} & \overline{v^2} & \overline{vw} \\ \overline{wu} & \overline{wv} & \overline{w^2} \end{pmatrix} \qquad (7)$$

These terms represent the effects of turbulent fluctuations on average flow and raise a problem of how to close the system of equations.

The system of equations is closed by employing a turbulence model. Given the anisotropic nature of flows within narrow, free-surface channels, a second-order turbulence model was indeed introduced. The Reynolds constraint equation is solved just like the average field equations. The second-order closing models serve to model several turbulence transport quantities, through a routine using the partial derivative equations: a constraint transport equation model (RSM) was chosen. In this case, the emphasis lies in solving the system of transport equations, which comprises six equations for the Reynolds constraints, plus another transport equation that involves a magnitude yielding a unit of length (or time). This magnitude often takes the form of a dissipation rate ε.

The Reynolds constraint transport equations are classically based on Equation **(8)**:

$$\frac{\partial\left(\overline{u_i u_j}\right)}{\partial t}+\frac{\partial}{\partial x_k}\left(U_k\,\overline{u_i u_j}\right)=P_{ij}+\phi_{ij}+\frac{\partial}{\partial x_k}\left[\left(\mu+\frac{2}{3}c_s\rho\frac{k^2}{\varepsilon}\right)\frac{\partial\overline{u_i u_j}}{\partial x_k}\right]-\frac{2}{3}\delta_{ij}\rho\varepsilon \qquad \textbf{(8)}$$

where P_{ij} is a production term and ϕ_{ij} the pressure-constraint term defined as follows:

$$P_{ij}=-\left[\overline{u_i u_k}\frac{\partial U_j}{\partial x_k}+\overline{u_j u_k}\frac{\partial U_i}{\partial x_k}\right] \qquad \textbf{(9)}$$

$$\phi_{ij}=\phi_{ij1}+\phi_{ij2}(4) \qquad \textbf{(10)}$$

$$\phi_{ij1}=-\rho\varepsilon\left(C_{s1}a+C_{s2}\left(a\bullet a-\frac{1}{3}a\bullet a\delta_{ij}\right)\right) \qquad \textbf{(11a)}$$

$$\phi_{ij2}=-C_{r1}Pa+C_{r2}\rho kS-C_{r3}\rho kS\sqrt{a\bullet a}+C_{r4}\rho k\left(aS^T+Sa^T-\frac{2}{3}a\bullet S\delta_{ij}\right)+C_{r5}\rho k\left(aW^T+Wa^T\right) \qquad \textbf{(11b)}$$

with:

$$a=\frac{\overline{u_i u_j}}{k}-\frac{2}{3}\delta_{ij} \qquad \textbf{(12)}$$

$$S=\frac{1}{2}\left(\frac{\partial U_i}{\partial x_j}+\frac{\partial U_j}{\partial x_i}\right) \qquad \textbf{(13)}$$

$$W=\frac{1}{2}\left(\frac{\partial U_i}{\partial x_j}-\frac{\partial U_j}{\partial x_i}\right) \qquad \textbf{(14)}$$

Let's note $P=\frac{P_{kk}}{2}$, $k=\frac{\overline{u_k u_k}}{2}$, the term a is the anisotropy tensor, the symbol $\bullet$ represents the matrix or tensor product, the term S the constraint tensor, W the turbulence eddy, and the exponent T signifies the matrix transpose. Model closure is completed by the equation involving turbulence dissipation rate ε, as provided by the relation in **(15)**.

$$\frac{\partial \varepsilon}{\partial t}+U_j\frac{\partial \varepsilon}{\partial x_j}=C_{\varepsilon 1}\frac{\varepsilon}{k}P_k-C_{\varepsilon 2}\frac{\varepsilon^2}{k}+\left[\frac{\partial}{\partial x_j}\left[\left(\nu+\nu_t/\sigma_\varepsilon\right)\frac{\partial \varepsilon}{\partial x_j}\right]-C_{\varepsilon 3}\frac{\varepsilon}{k}\frac{\partial}{\partial x_j}\left[\frac{\nu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right]\right] \quad \textbf{(15)}$$

where $P_k=\tau_{ij}\frac{\partial U_i}{\partial x_j}$ represents the turbulent energy produced during mean flow and τ_{ij} the shear constraints ($kg \cdot m^{-1} \cdot s^{-2}$).

Launder *et al.* **[11]** developed two distinct models for solving equations (Isotrope (LRR-IP), and Quasi-Isotrope (LRR-IQ)). Speziale *et al.* **[12]** proposed a more comprehensive model for solving these same equations (SSG turbulence model). We have decided to use this SSG model in the present study.

A hydrostatic pressure condition has been applied downstream and the flow near solid pipe walls modeled by means of the *wall function* **[11]**. Roughness has been set at 0.002 m and the modeling procedure carried out using a VOF (*volume of fluid*) method that allows representing the free surface. The numerical domain is biphasic.

NUMERICAL RESULTS

Modeling results indicate that as of a water height equal to 0.20 m, average velocity upstream of the weir exceeds 0.10 $m \cdot s^{-1}$, which means that the Doppler flow meter will be operable. The velocity field 5 m upstream of the weir was compared with the velocity field for the same water height in the absence of a weir. **Figure 4** shows that 5 m upstream of the weir, the weir exerted a negligible influence on the non-dimensional velocity field (U/U_{max}).

It is thereby considered that the site laid out with a V-shaped weir may be qualified for conducting measurements (Step 4 on **Figure 1**).

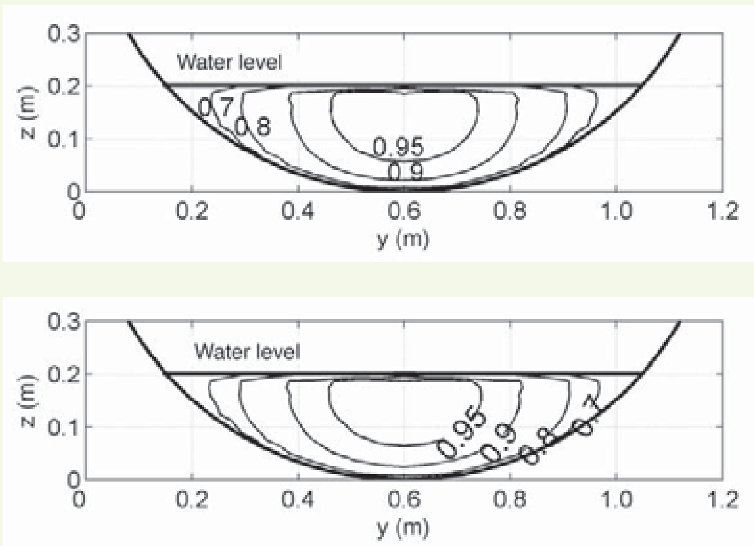
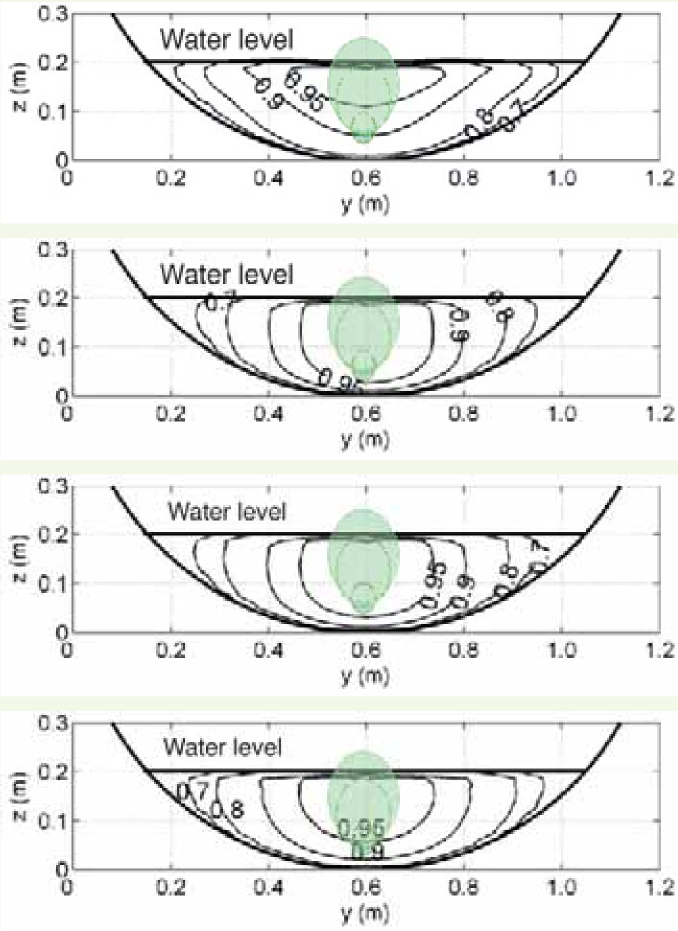


Figure 4
Influence of the V-shaped weir on the non dimensional velocity field (U/Umax) 5 m upstream
a: 5 m upstream of the V-shaped weir
b: without a weir

a
b

At this point, let's make the transition to the design stage (Step 5, **Figure 1**) and determine where exactly to place the flow meter upstream of the weir. **Figure 5** displays the intersection of velocity fields at various distances upstream of the weir with the ultrasonic cone of the Doppler flow meter based on the set of parameters identified by Larrarte *et al.* **[10]**. It can be observed that as of 2 m upstream of the weir, the ultrasonic beam cuts the same isovalue zones, i.e. those where velocity exceeds 0.90 U_{max}. This allows deducing that the flow meter may be installed between 2 and 5 m upstream of the weir if the goal is to obtain a measurement representative of the average velocity in the section.

Figure 5
Influence of the V-shaped weir on Doppler flow meter measurements
a: 1 m upstream of the V-shaped weir
b: 2 m upstream of the V-shaped weir
c: 3 m upstream of the V-shaped weir
d: 5 m upstream of the V-shaped weir



The results presented above now make it possible to determine the processing of acquired data using the Doppler flow meter. The measured velocity can in fact be influenced by the upstream distance from the weir, thus making it necessary to determine a correction coefficient that yields the average velocity U_{moy} in the section vs. velocity measured $U_{moycone}$ inside the cone. This coefficient K_U^{moy} is defined by the relation:

$$K_U^{moy} = \frac{U_{moy}}{U_{moy\,cone}} \tag{16}$$

It has been calculated that this coefficient equals 0.83 if the sensor is positioned 1 m upstream of the weir, 0.87 at 2 m upstream and 0.88 at 3 m upstream for a water height of 0.20 m.

INSTRUMENTATION AND MEASUREMENTS

Subsequent to the foregoing results, the V-shaped weir was installed within the stormwater drain pipe. **Figure 6** shows how the fastening work was performed.

The Doppler flow meter was positioned 5 m upstream of the weir. **Figure 7** presents an example of the measurements acquired during continuous operations. The subsequent analysis reveals that when water height surpasses 0.23 m, the velocities lie above 0.07 $m \cdot s^{-1}$ and the Doppler sensor operates properly. Comparisons with an electromagnetic current meter and a steel rule have enabled evaluating uncertainties at 0.01 m on the heights and 0.02 $m \cdot s^{-1}$ on the velocities.

Figure 6
Installation of the V-shaped weir

Figure 7
Evolution of velocities and heights in the presence of the V-shaped weir

When water height drops below 0.20 m, the sensor can no longer measure the very low velocities, and the calibration of a zero point curve Q = f(h) is underway. Now, the procedure requires taking measurements when the height lies between 0.20 and 0.22 m in order to describe the transition between the two situations. This work is ongoing yet will take a long time since such water heights correspond to rainfall events, which are extremely ephemeral events that do not lend themselves to experimental investigation **(Figure 7)**. An effort to quantify weir influence on the upstream velocity field and to generate velocity maps that allow verifying numerical results is planned, but has yet to commence.

In practice, the weir creates a dam, and a deposit forms upstream over a distance of at least tens of meters with a thickness of 0.05 to 0.06 m. Use of this equipment has provided satisfactory results during a six-month period but nonetheless required weekly maintenance. Since then, the probe first had to be changed since the velocity measurement proved defective. Next, fine particles (due to an overflow of cement in the collector pipe) made their way into the pressure probe used for measuring water heights, and the equipment had to be disassembled.

CONCLUSION

A methodology for qualifying measurement sites has been set forth **[6]**; it is based on a generic model that enables evaluating the zone of influence for various unique points and describing the ensuing velocity profile developed. Research is currently underway to compile a database of generic situations, such as flow downstream of an elbow.

In some cases, a specific complementary model is still required, as illustrated by the practical approach to the hydrological assessment of an urban catchment basin **[13]**. It proves necessary to measure flows at the outfall of the storm drain network, yet the low water heights prevent setting up a high-quality continuous measurement system. Numerical modeling capacities have been deployed in order to study the influence of a weir on the water surface profile and velocity field. Attention then turned to determining the distance upstream where the Doppler flow meter needed to be placed so as to ensure that the measured velocity was representative of the average section velocity. This effort led to instrumenting the drain pipe and generating six months of data, which are now being analyzed.

ACKNOWLEDGMENTS

The authors would like to thank the technical staff of LCPC's Water and Environment Division for their contribution to the experimental part of this project.

REFERENCES

1 **Mouchel J.-M.**, **Deutsch J.-C.**, **Chebbo G.**, **Andrieu H.**, **De Gouvello B.**, **Diab Y.**, L'hydrologie urbaine, une source pour la ville, *La Recherche-Ville et mobilité durables*, **2006**, **398**, pp. 32-34.

2 **AFNOR**, Norme NF EN 752-2, **1996**, 20 pages.

3 **AFNOR**, (1998), Norme NF EN 752-7, **1998**, 33 pages.

4 **AFNOR**, Norme NF P15-900-2, **2001**, 44 pages.

5 **Leclerc P.**, **Battaglia PH.**, Recommandations pratiques pour la conception de stations de mesure de débit, **TSM**, **2001**, **2**, pp. 45-56.

6 **Larrarte F.**, **Bonakdari H.**, **Joannis C.**, Effect of a bend on the velocity field in a circular sewer with free surface flow, *Novatech 2007*, Lyon, **2007**, tome **3**, pp. 1401-1408.

7 **Bertrand-Krajewski J.-L.**, **Laplace D.**, **Joannis C.**, **Chebbo G.**, Quelles mesures pour quels objectifs, *TSM*, **2001**, **2**, pp. 45-56.

8 **Le Gauffre P.**, **Joannis C.**, **Breysse D.**, **Gibello C.**, **Desmulliez J.-J.**, *Gestion patrimoniale des réseaux d'assainissement urbains - Guide méthodologique*, éditions Tec & Doc, **2004**, 395 pages.

9 **ChowV. T.**, *Open channel hydraulic*, McGraw-Hill, New York, **1959**, 680 pages.

10 **Larrarte F.**, **Bardiaux J.-B.**, **Battaglia P.**, **Joannis C.**, Vélocimétrie Doppler : mise au point d'un protocole d'essai en laboratoire, *TSM Techniques sciences méthodes*, génie urbain génie rural, **2006**, **6**, pp. 58 – 65.

11 **Launder B. E.**, **Spalding D. B.**, The numerical computation of turbulent flows, *Computational Methods Appl. Mech. Eng.*, **1974**, volume **3**, pp. 269-289.

12 **Speziale C.G.**, **Sarkar S.**, **Gatski T.B.**, Modelling the pressure-strain correlation of turbulence : an invariant dynamical systems approach, *Journal of Fluid Mechanics*, **1991**, volume **277**, pp 245-272.

13 **Ruban V.**, **Rodriguez F.**, **Rosant J.-M.**, **Larrarte F.**, **Joannis C.**, **Mestayer P.**, **Andrieu H.**, Hydrologic and energetic experimental survey of a small urban watershed, *Novatech 2007*, Lyon, **2007**, tome **3**, pp. 1189-1196.